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POSITION DETERMINATION WITH LORAN-C TRIPLETS AND THE TEXAS INST--ETC(U)
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POSITION DETERMINATION WITH LORAN-C TRIPLETS AND THE TEXAS INSTRUMENTS TI-59 PROGRAMMABLE CALCULATOR

by

R. H. Shudde

May 1980

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Prepared for:
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This report was prepared by:

Rex H. Shudde

REX H. SHUDDE, Associate Professor
Department of Operations Research

Reviewed by:

Michael G. Sovereign

MICHAEL G. SOVEREIGN,
Chairman
Department of Operations Research

Released by:

William M. Tolles

WILLIAM M. TOLLES,
Dean of Research

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This report presents an algorithm and TI-59 programs for position determination with Loran-C chains. Operational data cards are prepared in advance for Loran-C triplets. Position determination is performed using a single program card and an appropriate operational data card.

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ABSTRACT

This report presents an algorithm and TI-59 programs for position determination with Loran-C chains. Operational data cards are prepared in advance for Loran-C triplets. Position determination can be performed by using a single program card and an appropriate operational data card.

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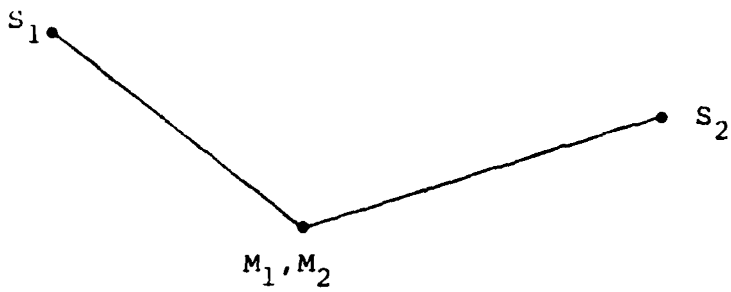
The programs in this report
are for use within the Navy,
and they are presented with-
out representation or warranty
of any kind.

CONTENTS

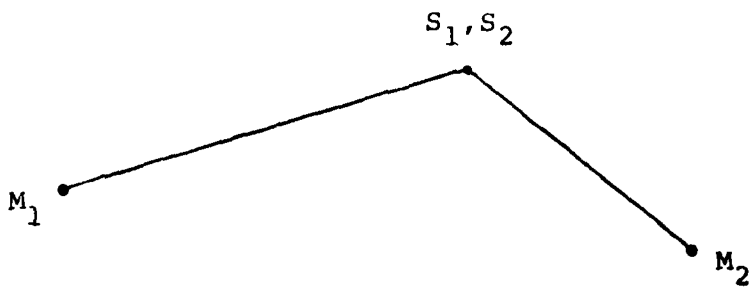
A. Introduction

The Loran system is a radio aid to navigation which utilizes the principle of hyperbolic fixing. The locus of points for which the difference in arrival time of synchronized signals from a pair of transmitters is constant determines a hyperbolic line of positions (LOP). The intersection of two hyperbolic lines of position from two pairs of transmitters (stations) determines a position estimate (a fix). That two lines of position and hence two pairs of stations are required for a fix does not necessarily mean that four separated stations are required, since one station of one pair may be colocated with one station of the other pair. In this case, a *Loran triplet* is formed (Figure 1). Triplets may be joined "end-to-end" by station colocation to form a *Loran chain* (Figure 2). Loran chains are common on both the East and West Coasts of the North American continent.

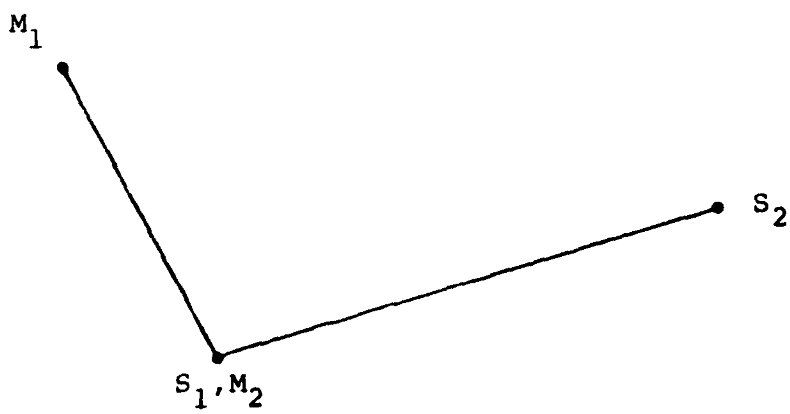
"Standard Loran" or "Loran-A" operates at a frequency just below 2 MHz and is now only used in the Pacific area. "Loran-C" operates at 100-kHz and is used both by ships and aircraft world wide. The computational algorithm and programs described herein can be used for position determination with Loran-C triplets. Further information on the history, development and operation of the Loran systems may be found in References 1 and 2.



(a) Colocated Master Stations



(b) Colocated Slave Stations



(c) Colocated Master and Slave

Figure 1. Loran Triplets.

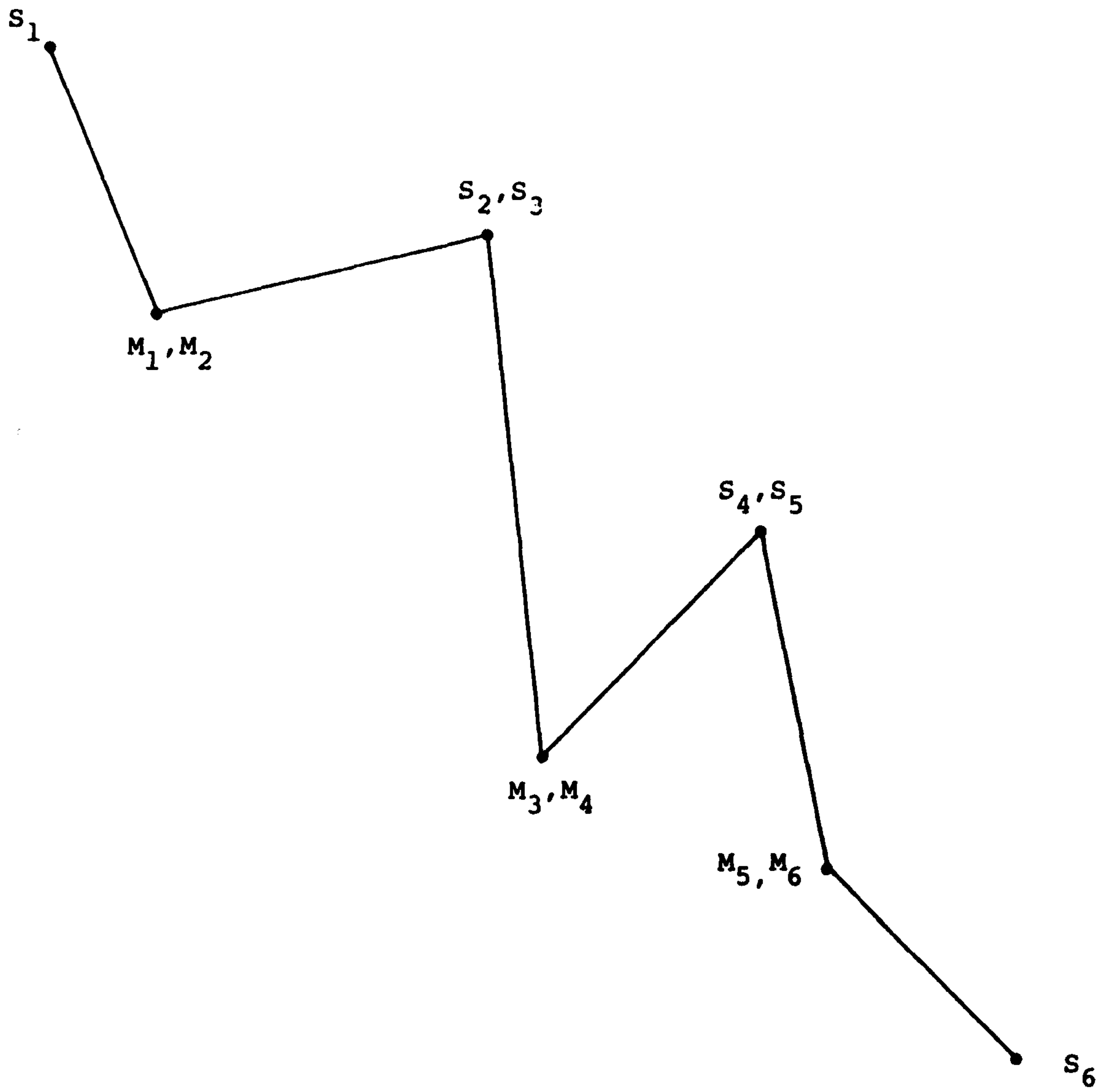


Figure 2. Loran Chain of Five Loran Triplets.

B. Program Description

The Position Determination Program requires operational data cards (described below) for on-location position determination from Loran triplet time-difference measurements. Two programs are used to prepare an operational data card. Operational data cards should be prepared and validated prior to on-location navigational use. Then, although three programs are used in total, only one program is required for position determination, the remaining two programs are used to prepare operational data cards.

The programs are:

Master Data Card Program: This program is used to prepare *master data cards*. A master data card requires the following information for a master (M) station/slave (S) station pair (a list of current station parameters is in the appendix):

1. A M/S pair identification number.
2. The quantity Δt which is the sum of the coding delay plus the one way base line time in microseconds.
3. The latitude and longitude of the master station.
4. The latitude and longitude of the slave station.

Some preprocessing of these data is performed before the master data card is generated. The data generated require only one side of a TI-59 magnetic card for each M/S pair, thus a second M/S pair may be placed on side 2 of a master data card. A master data card should be prepared in advance for each M/S pair that might be used within an area of operation.

Operational Data Card Program: This program is used to prepare an *operational data card* for each Loran triplet that might be used within an area of operation. Each operational data card contains data merged from two master data cards that contain the M/S pair information for each pair of a triplet. These merged data are validity checked, colocation of master or slave determined and encoded.

The inputs required to generate an operational data card for a Loran triplet using this program are those contained in the two master data cards that are associated with the triplet. It is possible to prepare and store operational data cards rather than master data cards. This may be desirable if there is no scarcity of cards and storage space, however the number of possible Loran triplets is considerably larger than the number of M/S pairs.

Position Determination Program: This program is used for position determination. The required inputs for the program are the indicated time differences T for the two M/S pairs of the triplet and the data contained in the operational data card associated with the triplet. The outputs of the program are the computed latitude and longitude of the Loran fix. Note: Every Loran determination gives two solutions: the proper solution and the spurious solution.

The spurious solution can almost always be rejected by inspection. However, if the stations of the Loran triplet are nearly aligned this may not be the case, and additional information will be required to determine the proper solution.

C. TI-59 Calculator Programs

1. User Instructions

Master Data Card Program (MDCP)

Step	Instructions	Input Data/Units	Keys	Output Data/Units
0.	Turn the calculator on. If the calculator has been on, turn it off, then on to initialize it.			
1.	Read side 1 of the MDCP program card.			
2.	Press CLR and then read side 2 of the MDCP program.		CLR	
3.	Input a unique ID number for the Loran pair. See Note a.	ID	2nd,A'	ID
4.	Input the coding delay Δt.	Δt	2nd,B'	Δt
5.	Input the master station latitude. See Note b.	ϕ_M	A	0
6.	Input the master station longitude. See Note b.	λ_M	B	0
7.	Input the slave station latitude.	ϕ_S	C	0
8.	Input the slave station longitude.	λ_S	D	0
9.	Run. When the calculations are complete, 4 will appear in the display; then the display will blank. After the display has blanked, enter a card in the read/write slot to record the master data card for the Loran pair. When the recording is complete, 4 will reappear in the display. See Note c.		E	

Notes: a. Loran pairs are coded on the navigation maps using designators such as 9930X, 9930Y, 9930Z and 9930W. It is suggested that the ID's for these pairs be coded as 9930.1, 9930.2, 9930.3 and 9930.4 respectively. However, any consistent scheme is acceptable.

b. The format for latitude and longitude data input is of the form: DDD.MMSSFF, where

DDD denotes degrees
MMM denotes minutes
SS denotes seconds
FF denotes hundredths of a second.

A minus sign (-) denotes South latitude and West longitude. See the Appendix with regard to the latter sign convention.

c. When the display has blanked after 4 has been displayed, the calculator is prepared to write a card side with the information (data) contained in bank 4. When a card is inserted, it will be recorded. Do not restrict the cards motion once the card has been grasped by the read/write mechanism. When recording is complete, the card will stop and 4 will reappear in the display. The card can then be removed.

Operational Data Card Program (ODCP)

Step	Instructions	Input Data/Units	Keys	Output Data/Units
0.	Turn the calculator on. If the calculator has been on, turn it off, then on to initialize it.			
1.	Read side 1 of the ODCP program card.			
2.	Press CLR and then read side 2 of the ODCP program card.		CLR	
3.	Press CLR and then read a master data card containing the first pair of a Loran triplet.		CLR	
4.	Press A.		A	
5.	Press CLR and then read a master data card containing the second pair of a Loran triplet.		CLR	
6.	Press B. See Note a.		B	
7.	Run. When the calculations are complete, 4 will appear in the display; then the display will blank. After the display has blanked, enter a card in the read/write slot to record an operational data card. When recording is complete, 4 will reappear in the display. See Note b.		E	

Notes: a. Should the display flash, then the two master data cards do not correspond to a Loran triplet. Both the latitude and longitude of the colocated stations must be identical on both master data cards in order to successfully produce an operational data card.

b. When the display has blanked after 4 has been displayed, the calculator is prepared to write a card side with the information (data) contained in bank 4; and, when a card is inserted, it will be recorded. Do not restrict the cards motion once the card has been grasped by the read/write mechanism. When recording is complete, the card will stop and 4 will reappear in the display. The card can then be removed.

Position Determination Program (PDP)

Step	Instructions	Input Data/Units	Keys	Output Data/Units
0.	Turn the calculator on. If the calculator has been on, then turn it off, then on to initialize it.			
1.	Read side 1 of the PDP program card.			
2.	Press CLR and then read side 2 of the PDP program card.		CLR	
3.	Press C to initialize, and then read the operational data card for a Loran triplet that you are receiving. See Note a below.		C	
4.	Input the observed time delay from the first Loran pair.	T_1	A	T_1
5.	Input the observed time delay from the second Loran pair.	T_2	B	T_2
6.	Compute the 1st solution latitude.		D	Latitude
7.	Compute the 1st solution longitude.		R/S	Longitude
8.	Compute the 2nd solution latitude.		E	Latitude
9.	Compute the 2nd solution longitude. See Note b.		R/S	Longitude
10.	To compute new solutions for new time delays, go to step 4. To compute new solutions for a new triplet, go to step 3.			

Note a. If the data card does not read (a flashing display results), press CLR and repeat the step. If the card does not read on the 2nd try, the card should be cleaned (see the TI-59 owners manual) or a new data card prepared.

Note b. Once the proper solution (solution 1 or solution 2) has been determined for a triplet, then only step 6 (for solution 1) or step 8 (for solution 2) need be repeated after inputing new time delays in step 4 and 5.

2. Example Problem for Loran-C Pairs 9930X and 9930Y

An example use of the Master Data Card Program using coding delays and latitude and longitude values from the Appendix:

Step	Instructions	Input Data/Units	Keys	Output Data/Units
0.	Turn the calculator on. If the calculator has been on, turn it off, then on. This assures that it will be in the correct initial state.			
1.	Read side 1 of the MDC program card.			
2.	Press CLR, then read side 2 of the MDC program card.		CLR	
3.	Input the ID for 9930X. Next press 2nd, then A.	9930.1	2nd,A'	9930.1
4.	Input the coding delay Δt for 9930X. Next press 2nd, then B.	36389.66	2nd,B'	36389.66
5.	Input the master station latitude, then press A.	34.034604	A	0
6.	Input the master station longitude and press +/- for West, then press B.	-77.544676	B	0
7.	Input the slave station latitude, then press C.	46.463218	C	0
8.	Input the slave station longitude and press +/- for West, then press D.	-53.102816	D	0
9.	Press E. After 4 has appeared in the display, enter an available card side in the read/write slot of the calculator. After recording is complete, 4 will reappear. Then remove the card and label the recorded side "9300X MASTER."		E	
10.	Input the ID for 9930Y, next press 2nd and then A.	9930.2	2nd,A'	9930.2

Step	Instructions	Input Data/Units	Keys	Output Data/Units
11.	Input the coding delay Δt for 9330Y, next press 2nd and then B.	52541.31	2nd,B'	52541.31
12.	Input the master station latitude, then press A.	34.034604	A	0
13.	Input the master station longitude and press +/- for West, then press B.	-77.544676	B	0
14.	Input the slave station latitude, then press C.	41.151193	C	0
15.	Input the slave station longitude, and press +/- for West, then press D.	-69.583909	D	0
16.	Press E. After 4 has appeared in the display, enter an available card side (for example the second side of the card used in Step 9) in the read/write slot of the calculator. After recording is complete, 4 will reappear in the display. Then remove the card and label the recorded side "9930Y MASTER." The recorded data cards (or card) will be used in the next example.		E	0

An example use of the Operational Data Card Program:

Step	Instructions	Input Data/Units	Keys	Output Data/Units
0.	Turn the calculator on. If the calculator has been on, turn it off, then on to initialize it.			
1.	Read side 1 of the ODCP program card.			
2.	Press CLR and then read side 2 of the ODCP Program Card.		CLR	
3.	Press CLR and then read the master data card for station 9330X.		CLR	
4.	Press A.		A	
5.	Press CLR and then read the master data card for station 9930Y.		CLR	
6.	Press B. See Note a of the ODCP instructions on page 9.		B	
7.	Press E. When the display has blanked after 4 has appeared, insert an available card side in the read/write slot. After recording is complete, 4 will reappear in the display. Label the recorded card side "9330X/9930Y OPERATIONAL DATA. Then, for identification, label the A key position on the card "9330X" and the B key position "9330Y". This card will be used as the data card in the Position Determination Program example. The key labeling relates to that program.		E	

An example use of the Position Determination Program:

Step	Instructions	Input Data/Units	Keys	Output Data/Units
	You are in the North Atlantic and you are receiving 9930X and 9930Y and you wish to obtain a fix.			
0.	Turn the calculator on. If the calculator has been on, then turn it off, then on to initialize it.			
1.	Read side 1 of the PDP program card.			
2.	Press CLR and then read side 2 of the PDP program card.		CLR	
3.	Press C to initialize, and then read the operational data for the triplet 9930X/9930Y from the card side recorded in the ODCP example.		C	
4.	The indicated time delay is 28800 μs from 9930X. Input the indicated time delay, then press A.	28800	A	28800
5.	The indicated time delay is 49400 μs from 9930Y. Input the indicated time delay, then press B.	49400	B	49400
6.	Press D to obtain the 1st solution latitude.		D	42.4457
7.	Press R/S to obtain the 1st solution longitude.		R/S	-41.0732
	The first solution is: 42°44'57"N Latitude 41°07'32"W Longitude			
8.	Press E to obtain the 2nd solution latitude.		E	-27.0007
9.	Press R/S to obtain the 2nd solution longitude.		R/S	102.2712
	The 2nd solution is: 27°00'07"S Latitude 102°27'12"E Longitude			

3. Program Listings

Master Data Card Program

```
000  76  LBL
001  42  STO
002  72  ST*
003  00   00
004  97  DSZ
005  00   00
006  42  STO
007  00   0
008  22  INV
009  58  FIX
010  04   4
011  66  PAU
012  66  PAU
013  66  PAU
014  66  PAU
015  66  PAU
016  96  WRT
017  92  RTN
018  76  LBL
019  17  B'
020  42  STO
021  29   29
022  92  RTN
023  76  LBL
024  16  A'
025  42  STO
026  28   28
027  92  RTN
028  76  LBL
029  11   A
030  32  X:T
031  02   2
032  03   3
033  61  GTO
034  85   +
035  76  LBL
036  13   C
037  32  X:T
038  02   2
039  05   5
040  76  LBL
041  85   +
042  42  STO
043  00   00
044  32  X:T
045  88  DMS
046  30  TAN
047  65   ×
048  53   (
049  01   1
050  75   -
051  02   2
052  09   9
053  09   9
054  93   .
055  02   2
056  06   6
057  35  1/X
058  42  STO
059  20   20
060  95   =
061  22  INV
062  30  TAN
063  72  ST*
064  00   00
065  00   0
066  92  RTN
067  76  LBL
068  12   B
069  88  DMS
070  42  STO
071  22   22
072  00   0
073  92  RTN
074  76  LBL
075  14   D
076  88  DMS
077  42  STO
078  24   24
079  00   0
080  92  RTN
081  76  LBL
082  15   E
083  43  RCL
084  23   23
085  85   +
086  43  RCL
087  25   25
088  95   =
089  55   ÷
090  02   2
091  95   =
092  42  STO
093  00   00
094  43  RCL
095  25   25
096  75   -
097  43  RCL
098  23   23
099  95   =
100  55   ÷
101  02   2
102  95   =
103  42  STO
104  01   01
105  43  RCL
106  24   24
107  75   -
108  43  RCL
109  22   22
110  95   =
111  42  STO
112  02   02
113  55   ÷
114  02   2
115  95   =
116  42  STO
117  03   03
118  38  SIN
119  33  X²
120  65   ×
121  43  RCL
122  23   23
123  39  COS
124  65   ×
125  43  RCL
126  25   25
127  39  COS
128  85   +
129  43  RCL
130  01   01
131  38  SIN
132  33  X²
133  95   =
134  42  STO
135  04   04
136  65   ×
137  02   2
138  94  +/-
139  85   +
140  01   1
141  95   =
142  22  INV
143  39  COS
144  42  STO
145  13   13
146  43  RCL
147  00   00
148  38  SIN
149  65   ×
```

Master Data Card Program (continued)

150	43	RCL
151	01	01
152	39	COS
153	95	=
154	33	X^2
155	65	×
156	02	2
157	55	÷
158	53	(
159	01	1
160	75	-
161	43	RCL
162	04	04
163	95	=
164	42	STO
165	06	06
166	43	RCL
167	01	01
168	38	SIN
169	65	×
170	43	RCL
171	00	00
172	39	COS
173	95	=
174	33	X^2
175	65	×
176	02	2
177	55	÷
178	43	RCL
179	04	04
180	95	=
181	42	STO
182	07	07
183	85	+
184	43	RCL
185	06	06
186	95	=
187	42	STO
188	08	08
189	43	RCL
190	06	06
191	75	-
192	43	RCL
193	07	07
194	95	=
195	42	STO
196	09	09
197	43	RCL
198	13	13
199	55	÷

200	43	RCL
201	13	13
202	38	SIN
203	65	×
204	89	π
205	55	÷
206	01	1
207	08	8
208	00	0
209	95	=
210	42	STO
211	05	05
212	65	×
213	43	RCL
214	08	08
215	75	-
216	43	RCL
217	09	09
218	95	=
219	65	×
220	43	RCL
221	20	20
222	55	÷
223	04	4
224	95	=
225	42	STO
226	11	11
227	94	+/-
228	85	+
229	43	RCL
230	05	05
231	95	=
232	65	×
233	43	RCL
234	13	13
235	38	SIN
236	95	=
237	42	STO
238	26	26
239	43	RCL
240	09	09
241	75	-
242	53	(
243	01	1
244	75	-
245	02	2
246	65	×
247	43	RCL
248	04	04
249	54	)

250	65	×
251	53	(
252	04	4
253	75	-
254	43	RCL
255	08	08
256	54	)
257	95	=
258	65	×
259	43	RCL
260	20	20
261	65	×
262	43	RCL
263	05	05
264	65	×
265	43	RCL
266	02	02
267	30	TAN
268	65	×
269	04	4
270	05	5
271	55	÷
272	89	π
273	94	+/-
274	85	+
275	43	RCL
276	02	02
277	95	=
278	55	÷
279	02	2
280	95	=
281	42	STO
282	12	12
283	38	SIN
284	65	×
285	43	RCL
286	00	00
287	39	COS
288	95	=
289	32	X⇌T
290	43	RCL
291	12	12
292	39	COS
293	65	×
294	43	RCL
295	01	01
296	38	SIN
297	95	=
298	94	+/-
299	22	INV

Master Data Card Program (continued)

300	37	P/R
301	42	STO
302	21	21
303	42	STO
304	27	27
305	01	1
306	32	X:T
307	43	RCL
308	12	12
309	37	P/R
310	65	×
311	43	RCL
312	00	00
313	38	SIN
314	95	=
315	32	X:T
316	65	×
317	43	RCL
318	01	01
319	39	COS
320	95	=
321	22	INV
322	37	P/R
323	44	SUM
324	21	21
325	22	INV
326	44	SUM
327	27	27
328	01	1
329	03	3
330	42	STO
331	00	00
332	00	0
333	61	GTO
334	42	STO
335	00	0
336	00	0
337	00	0
338	00	0
339	00	0
340	00	0
341	00	0
342	00	0

Operational Data Card Program

Step	Code	Key
000	76	LBL
001	42	STO
002	73	RC*
003	01	01
004	72	ST*
005	02	02
006	69	OP
007	31	31
008	69	OP
009	32	32
010	97	DSZ
011	00	00
012	42	STO
013	92	RTN
014	76	LBL
015	11	A
016	09	9
017	42	STO
018	00	00
019	02	2
020	09	9
021	42	STO
022	01	01
023	03	3
024	09	9
025	42	STO
026	02	02
027	71	SBR
028	42	STO
029	00	0
030	92	RTN
031	76	LBL
032	12	B
033	09	9
034	42	STO
035	00	00
036	02	2
037	09	9
038	42	STO
039	01	01
040	01	1
041	09	9
042	42	STO
043	02	02
044	71	SBR
045	42	STO
046	00	0
047	92	RTN
048	76	LBL
049	15	E
050	09	9
051	42	STO
052	00	00
053	03	3
054	09	9
055	42	STO
056	01	01
057	02	2
058	09	9
059	42	STO
060	02	02
061	71	SBR
062	42	STO
063	43	RCL
064	22	22
065	32	X:T
066	43	RCL
067	12	12
068	22	INV
069	67	EQ
070	85	+
071	43	RCL
072	23	23
073	32	X:T
074	43	RCL
075	13	13
076	67	EQ
077	44	SUM
078	76	LBL
079	85	+
080	43	RCL
081	24	24
082	32	X:T
083	43	RCL
084	14	14
085	22	INV
086	67	EQ
087	75	-
088	43	RCL
089	25	25
090	32	X:T
091	43	RCL
092	15	15
093	22	INV
094	67	EQ
095	75	-
096	71	SBR
097	32	X:T
098	71	SBR
099	37	P/R
100	61	GTO
101	44	SUM
102	76	LBL
103	75	-
104	43	RCL
105	22	22
106	32	X:T
107	43	RCL
108	14	14
109	67	EQ
110	65	×
111	43	RCL
112	23	23
113	32	X:T
114	43	RCL
115	15	15
116	22	INV
117	67	EQ
118	65	×
119	71	SBR
120	37	P/R
121	61	GTO
122	44	SUM
123	76	LBL
124	65	×
125	43	RCL
126	12	12
127	32	X:T
128	43	RCL
129	24	24
130	22	INV
131	67	EQ
132	55	÷
133	43	RCL
134	13	13
135	32	X:T
136	43	RCL
137	25	25
138	22	INV
139	67	EQ
140	55	÷
141	71	SBR
142	32	X:T
143	76	LBL
144	44	SUM
145	00	0
146	42	STO
147	00	00
148	42	STO
149	01	01

Operational Data Program Card (continued)

150	42	STO
151	02	02
152	02	2
153	01	1
154	02	2
155	09	9
156	05	5
157	93	.
158	08	8
159	07	7
160	42	STO
161	10	10
162	22	INV
163	58	FIX
164	04	4
165	66	PAU
166	66	PAU
167	66	PAU
168	66	PAU
169	66	PAU
170	96	WRT
171	92	RTN
172	76	LBL
173	32	X↕T
174	43	RCL
175	21	21
176	32	X↕T
177	43	RCL
178	27	27
179	42	STO
180	21	21
181	32	X↕T
182	42	STO
183	27	27
184	43	RCL
185	22	22
186	32	X↕T
187	43	RCL
188	24	24
189	42	STO
190	22	22
191	32	X↕T
192	42	STO
193	24	24
194	43	RCL
195	23	23
196	32	X↕T
197	43	RCL
198	25	25
199	42	STO
200	23	23
201	32	X↕T
202	42	STO
203	25	25
204	43	RCL
205	28	28
206	94	+/-
207	42	STO
208	28	28
209	92	RTN
210	76	LBL
211	37	P/R
212	43	RCL
213	11	11
214	32	X↕T
215	43	RCL
216	17	17
217	42	STO
218	11	11
219	32	X↕T
220	42	STO
221	17	17
222	43	RCL
223	12	12
224	32	X↕T
225	43	RCL
226	14	14
227	42	STO
228	12	12
229	32	X↕T
230	42	STO
231	14	14
232	43	RCL
233	23	23
234	32	X↕T
235	43	RCL
236	15	15
237	42	STO
238	13	13
239	32	X↕T
240	42	STO
241	15	15
242	43	RCL
243	18	18
244	94	+/-
245	42	STO
246	18	18
247	92	RTN
248	76	LBL
249	55	÷
250	00	0
251	00	0
252	00	0
253	00	0
254	00	0
255	00	0
256	00	0
257	00	0
258	00	0
259	00	0
260	00	0
261	00	0

Position Determination Program

000	76	LBL
001	13	C
002	22	INV
003	58	FIX
004	00	0
005	92	RTN
006	76	LBL
007	11	A
008	32	X:T
009	02	2
010	09	9
011	61	GTO
012	85	+
013	76	LBL
014	12	B
015	32	X:T
016	01	1
017	09	9
018	76	LBL
019	85	+
020	70	RAD
021	42	STO
022	00	00
023	32	X:T
024	42	STO
025	59	59
026	75	-
027	73	RC*
028	00	00
029	95	=
030	55	÷
031	43	RCL
032	10	10
033	95	=
034	32	X:T
035	69	OP
036	30	30
037	73	RC*
038	00	00
039	69	OP
040	10	10
041	69	OP
042	30	30
043	72	ST*
044	00	00
045	01	1
046	32	X:T
047	37	P/R
048	64	PD*
049	00	00
050	32	X:T
051	75	-
052	01	1
053	32	X:T
054	69	OP
055	30	30
056	73	RC*
057	00	00
058	37	P/R
059	69	OP
060	30	30
061	72	ST*
062	00	00
063	69	OP
064	30	30
065	32	X:T
066	95	=
067	72	ST*
068	00	00
069	43	RCL
070	59	59
071	92	RTN
072	76	LBL
073	14	D
074	86	STF
075	00	00
076	61	GTO
077	55	÷
078	76	LBL
079	15	E
080	22	INV
081	86	STF
082	00	00
083	76	LBL
084	55	÷
085	00	0
086	42	STO
087	01	01
088	42	STO
089	04	04
090	60	DEG
091	43	RCL
092	24	24
093	65	×
094	43	RCL
095	15	15
096	95	=
097	32	X:T
098	43	RCL
099	11	11
100	37	P/R
101	78	Σ+
102	43	RCL
103	14	14
104	65	×
105	43	RCL
106	25	25
107	95	=
108	32	X:T
109	43	RCL
110	21	21
111	37	P/R
112	22	INV
113	78	Σ+
114	43	RCL
115	04	04
116	32	X:T
117	43	RCL
118	01	01
119	22	INV
120	37	P/R
121	42	STO
122	09	09
123	43	RCL
124	14	14
125	65	×
126	43	RCL
127	27	27
128	75	-
129	43	RCL
130	17	17
131	65	×
132	43	RCL
133	24	24
134	95	=
135	55	÷
136	32	X:T
137	95	=
138	22	INV
139	39	COS
140	87	IFF
141	00	00
142	75	-
143	94	+/-
144	76	LBL
145	75	-
146	44	SUM
147	09	09
148	43	RCL
149	09	09

Position Determination Program (continued)

150	75	-
151	43	RCL
152	21	21
153	95	=
154	39	COS
155	65	×
156	43	RCL
157	25	25
158	85	+
159	43	RCL
160	27	27
161	95	=
162	32	X:T
163	43	RCL
164	24	24
165	22	INV
166	37	P/R
167	42	STO
168	08	08
169	43	RCL
170	23	23
171	39	COS
172	32	X:T
173	43	RCL
174	09	09
175	37	P/R
176	42	STO
177	00	00
178	65	×
179	43	RCL
180	20	20
181	95	=
182	42	STO
183	02	02
184	01	1
185	75	-
186	43	RCL
187	00	00
188	33	X^2
189	95	=
190	55	÷
191	04	4
192	65	×
193	43	RCL
194	20	20
195	95	=
196	42	STO
197	03	03
198	65	×
199	02	2
200	94	+/-
201	85	+
202	01	1
203	75	-
204	43	RCL
205	02	02
206	65	×
207	43	RCL
208	00	00
209	95	=
210	35	1/X
211	49	PRD
212	03	03
213	49	PRD
214	08	08
215	43	RCL
216	23	23
217	38	SIN
218	32	X:T
219	42	STO
220	01	01
221	22	INV
222	37	P/R
223	75	-
224	43	RCL
225	08	08
226	95	=
227	65	×
228	02	2
229	95	=
230	42	STO
231	04	04
232	85	+
233	43	RCL
234	08	08
235	95	=
236	39	COS
237	42	STO
238	05	05
239	01	1
240	75	-
241	43	RCL
242	04	04
243	39	COS
244	65	×
245	02	2
246	65	×
247	43	RCL
248	03	03
249	95	=
250	65	×
251	43	RCL
252	08	08
253	38	SIN
254	65	×
255	02	2
256	65	×
257	43	RCL
258	03	03
259	65	×
260	43	RCL
261	05	05
262	65	×
263	01	1
264	08	8
265	00	0
266	55	÷
267	89	π
268	95	=
269	22	INV
270	44	SUM
271	08	08
272	43	RCL
273	23	23
274	38	SIN
275	65	×
276	43	RCL
277	08	08
278	39	COS
279	85	+
280	43	RCL
281	01	01
282	65	×
283	43	RCL
284	08	08
285	38	SIN
286	95	=
287	42	STO
288	07	07
289	01	1
290	32	X:T
291	43	RCL
292	08	08
293	37	P/R
294	65	×
295	43	RCL
296	23	23
297	38	SIN
298	94	+/-
299	85	+

Position Determination Program (continued)

```
300  43  RCL
301  01   01
302  65   ×
303  32  X:T
304  95   =
305  33  X²
306  85   +
307  43  RCL
308  00   00
309  33  X²
310  95   =
311  34  √X
312  65   ×
313  53   (
314  01   1
315  75   -
316  43  RCL
317  20   20
318  95   =
319  35  1/X
320  65   ×
321  43  RCL
322  07   07
323  95   =
324  22  INV
325  30  TAN
326  42  STO
327  07   07
328  43  RCL
329  23   23
330  39  COS
331  65   ×
332  43  RCL
333  08   08
334  39  COS
335  75   -
336  43  RCL
337  23   23
338  38  SIN
339  65   ×
340  43  RCL
341  08   08
342  38  SIN
343  65   ×
344  43  RCL
345  09   09
346  39  COS
347  95   =
348  32  X:T
349  43  RCL
350  08   08
351  38  SIN
352  65   ×
353  43  RCL
354  09   09
355  38  SIN
356  95   =
357  22  INV
358  37  P/R
359  75   -
360  43  RCL
361  02   02
362  65   ×
363  43  RCL
364  08   08
365  85   +
366  43  RCL
367  22   22
368  95   =
369  32  X:T
370  01   1
371  32  X:T
372  37  P/R
373  22  INV
374  37  P/R
375  42  STO
376  06   06
377  32  X:T
378  01   1
379  08   8
380  00   0
381  77  GE
382  65   ×
383  65   ×
384  02   2
385  94  +/-
386  85   +
387  32  X:T
388  95   =
389  42  STO
390  06   06
391  76  LBL
392  65   ×
393  43  RCL
394  06   06
395  22  INV
396  88  DMS
397  32  X:T
398  43  RCL
399  07   07
400  22  INV
401  88  DMS
402  58  FIX
403  04   04
404  91  R/S
405  32  X:T
406  91  R/S
407  00   0
408  00   0
409  00   0
410  00   0
411  00   0
412  00   0
413  00   0
414  00   0
415  00   0
416  00   0
417  00   0
418  00   0
420  00   0
421  00   0
422  00   0
423  00   0
424  00   0
425  00   0
```

D. Loran-C Fixing Algorithms

The development of the Loran fixing algorithms in this report is presented in more detail in a companion report [Ref. 3] and will not be repeated here.

The basic Loran-C equation [Ref. 4] can be written as

$$T = [T_S + p(T_S)] - [T_M + p(T_M)] + [T_B + p(T_N)] + \delta \qquad (1)$$

where

- T is the "indicated time difference" in microseconds,
- T_M, T_S is the distance, in microseconds, from the master and the slave to the receiver, respectively,
- T_B is the distance, in microseconds, between the master and the slave,
- δ is the assigned coding delay, in microseconds, and
- $p(T)$ is the secondary phase correction, in microseconds, for an all sea water path of length T.

The quantity

$$\Delta t = [T_B + p(T_B)] + \delta$$

is a constant for each master/slave pair. The following World Geodetic System 1972 (WGS 72) values have been adopted for Loran-C navigation [Ref. 4]:

v_0 = 299792458 meters/second is the velocity of light in free space,

η = 1.000338 is the index of refraction of the surface of the earth for standard atmosphere and 100kHz electromagentic waves,

a_e = 6378135.00 meters is the equatorial radius of the earth, and

f = 1/298.26 is the flattening factor (1 - b/a_e, where b is the polar radius) of the earth.

Accurate formulas for computing the secondary phase correction p(T) are contained in Reference 4, but for use with the handheld calculator the following linear approximation [Ref. 3] will be used:

$$p(T) = a_1 + a_2T \ ,$$

where

$$a_1 = -0.321,$$

and

$$a_2 = \ 0.000635.$$

Using this approximation, it is possible to solve Equation 1 for the quantity $T_S - T_M$. We find

$$T_S - T_M = (T - \Delta t)/(1 + a_2) \ . \qquad (2)$$

On the surface of a sphere a hyperbolic line of position can be represented by the equation [Ref. 3, page 175]

$$\tan r = \frac{\cos 2a - \cos 2c}{\sin 2c \cos \omega + \zeta \sin 2a} \qquad (3)$$

where the origin of the coordinate system is at the prime focus of the spherical hyperbola, $2c$ is the spherical arc joining the foci, $2a$ is a constant for any one LOP, and r and ω are the spherical coordinates of a point on the LOP. If the base line of the coordinate system is the arc joining the foci then ω is the spherical polar angle from the base line to a point P on the LOP and r is the spherical polar distance (or arc) from the prime focus to P. Using the Loran system we take $\zeta = +1$ if the prime focus is at a master station and we take $\zeta = -1$ if the prime focus is at a slave station.

If we take $v = v_0/\eta$ to be the velocity of 100kHz electromagnetic radiation of the earth's surface then

$$2a = v(T_S - T_M)/a_e ,$$

or, using Eq. (2),

$$2a = (T - \Delta t)/a_p , \qquad (4)$$

where

$$a_p = \frac{a_e(1 + a_2)}{v_0/\eta} = 21295.87 \ \mu s .$$

The baseline between master and slave can be obtained from

$$2c = v \, T_B/a_e . \qquad (5)$$

Here $2c$ is computed by program card 1 (preparation of master data cards) using the algorithm in Section E.

Consider a Loran-C triplet with master stations colocated. Let ξ_1 and ξ_2 denote the azimuth angles of slave 1 (S_1) and slave 2 (S_2), respectively, measured from North toward the East from the master stations (M) (see Fig. 3). Further, let α and r denote the azimuth and spherical polar arc (distance) of the receiver (R) from M. For this geometry, Eq. (3) can be written as

$$\tan r_i = \frac{B_i}{C_i \cos(\alpha - \xi_i) + A_i} \tag{6}$$

where

$$A_i = \zeta_i \sin 2a_i$$

$$B_i = \cos 2a_i - \cos 2c_i$$

and

$$C_i = \sin 2c_i$$

for the $i^{\underline{th}}$ Loran pair, $i = 1,2$. Since $r = r_1 = r_2$, $\tan r_i$ can be eliminated in Eq. (6). The resulting equation can be rewritten as

$$C \cos \alpha + S \sin \alpha = K , \tag{7}$$

where

$$C = B_1C_2 \cos \xi_2 - B_2C_1 \cos \xi_1,$$

$$S = B_1C_2 \sin \xi_2 - B_2C_1 \sin \xi_1,$$

and

$$\kappa = B_2A_1 - B_1A_2 .$$

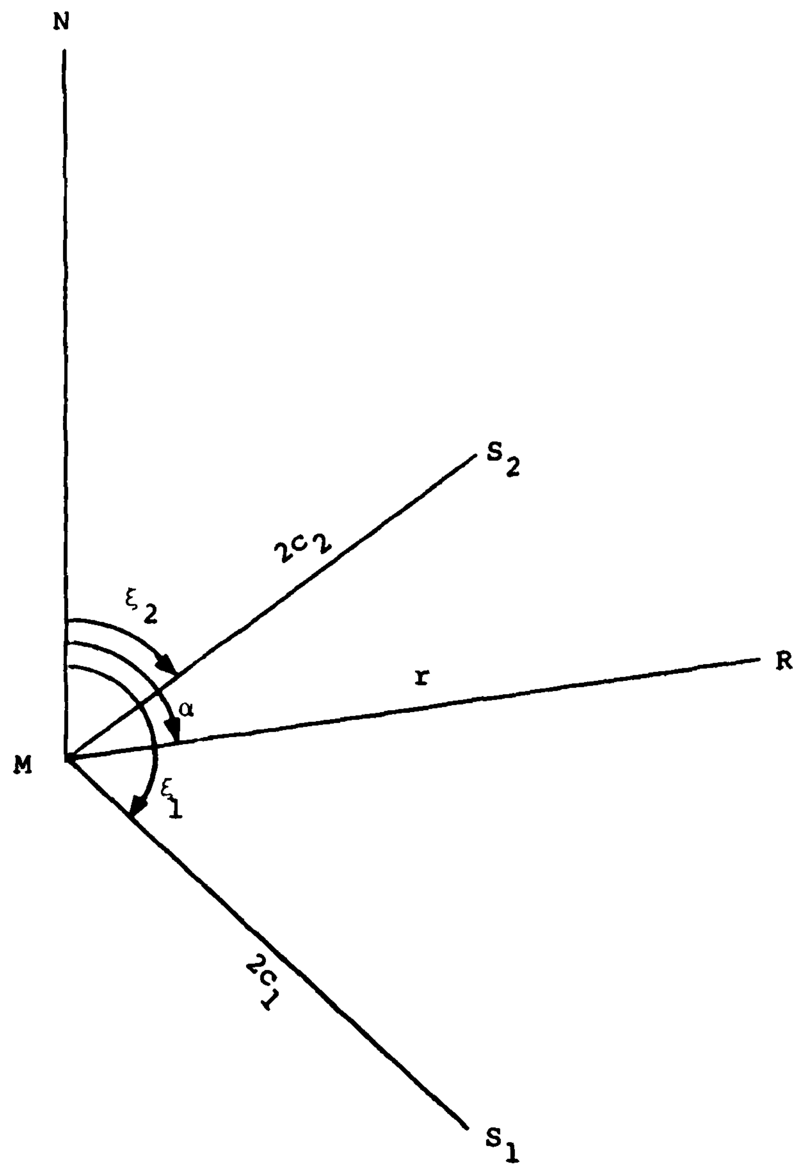


Figure 3. Geometry of a Loran Triplet and a Receiver.

If we define $\rho > 0$ and γ by the equations

and
$$\begin{aligned} \rho \cos \gamma &= C, \\ \rho \sin \gamma &= S, \end{aligned} \tag{8}$$

then

$$\rho = \sqrt{C^2 + S^2} ,$$

and

$$\gamma = \text{qatn}(S,C) .$$

Here the function qatn(y,x) is the arctangent of y/x adjusted for the proper quadrant according to the signs of x and y. A compact form of this function is

$$\text{qatn}(y,x) = \tan^{-1} \frac{y}{x + 10^{-9} t(x = 0?)} + \pi t(x < 0?)$$

where

$t(z) = 1$ when z is true

and

$t(z) = 0$ when z is false.

When convenient we will use the notation qatn(y/x) interchangeably with qatn(y,x). The qatn function is equivalent to the polar angle obtained using the rectangular to polar conversion function on the TI-59.

Now substitute Eq. (8) into Eq. (7) and solve for

$$\alpha = \gamma \pm \cos^{-1}(\kappa/\rho) \tag{9}$$

to obtain the azimuth angle α of the two points of intersection of the LOP's. Finally we obtain a value for r by substituting each α into Eq. (5). We find that

$$r = \text{qatn}\left[\frac{B_i}{C_i \cos(\alpha-\xi_i) + A_i}\right] \quad \text{for} \quad i = 1 \text{ or } 2.$$

The distance and azimuth from M or the triplet vertex can be converted into the latitude and longitude of the two possible positions of R.

The fixing algorithm then uses α and r in the *direct* solution algorithm of spheroidal geodesy (Section F).

E. The Reverse (Inverse) Solution Algorithm

This *reverse* solution algorithm is a modification of the first order in flattening (f) algorithm given by Thomas [Ref. 5, pp. 8-10]. Thomas' notation has been followed as closely as possible for ease of comparison of the algorithms. The qatn function is defined in Section D. West longitudes (λ) and South latitudes (ϕ) are negative. We are given the points $P_1(\phi_1, \lambda_1)$, $P_2(\phi_2, \lambda_2)$ on the spheroid and are to find the distance S between the points and the forward and back azimuths, α_{12} and α_{21}. Given quantities are ϕ_1, λ_1, ϕ_2 and λ_2. No assumptions about the relative location of P_1 and P_2 are required. The modified *reverse* solution algorithm is:

$$\theta_i = \tan^{-1}[(1-f)\tan\phi_i], \quad i = 1, 2,$$

$$\theta_m = (\theta_1 + \theta_2)/2, \quad \Delta\theta_m = (\theta_2 - \theta_1)/2, \quad \Delta\lambda = \lambda_2 - \lambda_1,$$

$$\Delta\lambda_m = \Delta\lambda/2, \quad H = \cos^2\Delta\theta_m - \sin^2\theta_m = \cos^2\theta_m - \sin^2\Delta\theta_m = \cos\theta_1\cos\theta_2,$$

$$L = \sin^2\Delta\theta_m + H\sin^2\Delta\lambda_m = \sin^2(d/2), \quad 1 - L = \cos^2(d/2),$$

$$d = \cos^{-1}(1 - 2L), \quad U = 2\sin^2\theta_m\cos^2\Delta\theta_m/(1 - L),$$

$$V = 2\sin^2\Delta\theta_m\cos^2\theta_m/L, \quad X = U + V, \quad Y = U - V,$$

$$T = d/\sin d, \quad \delta_1 d = f(TX - Y)/4, \quad S = a_e(T - \delta_1 d)\sin d,$$

$$F = 2[Y - (1 - 2L)(4 - X)], \quad G = fT/2,$$

$$Q = -(FG\tan\Delta\lambda)/4, \quad \Delta\lambda'_m = (\Delta\lambda + Q)/2$$

$$t_1 = \mathrm{qatn}(-\sin \Delta\theta_m \cos \Delta\lambda'_m,\ \cos \theta_m \sin \Delta\lambda'_m),$$

$$t_2 = \mathrm{qatn}(\cos \Delta\theta_m \cos \Delta\lambda'_m,\ \sin \theta_m \sin \Delta\lambda'_m),$$

$$\alpha_{12} = t_1 + t_2, \quad \alpha_{21} = t_1 - t_2 .$$

This reverse solution algorithm is used by program card 1 (preparation of master data cards) to compute the baseline distance $2c$ and the azimuths ε_{MS} and ε_{SM} between the master and slave stations of a Loran pair.

Details of the modifications made to Thomas' algorithm are contained in Reference 3.

F. The Direct Solution Algorithm

This *direct* solution algorithm is a modification of the first order in flattening (f) algorithm given by Thomas [Ref. 5, pp. 7-8]. Thomas' notation has been followed as closely as possible for ease of comparison of the algorithms. The qatn function is defined in Section D. West longitudes and South latitudes are negative. We are given the point $P_1(\phi_1, \lambda_1)$ on the spherioid, where ϕ_1, λ_1 are the geodetic latitude and longtiude (geographic coordinates); the forward azimuth α_{12} and the distance S to a second point $P_2(\phi_2, \lambda_2)$; and from these we are to find the geographic coordinates ϕ_2, λ_2 and the back azimuth α_{21}. The given quantities are ϕ_1, λ_1, α_{12} and S. No assumptions about the relative location of P_1 and P_2 are required. The modified *direct* solution algorithm is:

$$\theta_1 = \tan^{-1}[(1-f)\tan\phi_1], \quad M = \cos\theta_1 \sin\alpha_{12}$$

$$N = \cos\theta_1 \cos\alpha_{12}, \quad c_1 = fM, \quad c_2 = f(1 - M^2)/4,$$

$$D = 1 - 2c_2 - c_1 M, \quad P = c_2/D, \quad \sigma_1 = \mathrm{qatn}(N, \sin\theta_1)$$

$$d = S/(a_e D), \quad u = 2(\sigma_1 - d), \quad W = 1 - 2P\cos u,$$

$$V = \cos(u + d), \quad Y = 2PVW \sin d, \quad \Delta\sigma = d - Y,$$

$$\alpha_{21} = \mathrm{qatn}[-M, -(N\cos\Delta\sigma - \sin\theta_1 \sin\Delta\sigma)],$$

$$K = (1-f)[M^2 + (N\cos\Delta\sigma - \sin\theta_1 \sin\Delta\sigma)^2]^{1/2},$$

$$\phi_2 = \tan^{-1}[(\sin\theta_1 \cos\Delta\sigma + N\sin\Delta\sigma)/K],$$

$$\Delta\eta = \mathrm{qatn}(\sin\Delta\sigma \sin\alpha_{12}, \cos\theta_1 \cos\Delta\sigma - \sin\theta_1 \sin\Delta\sigma \cos\alpha_{12}),$$

$$H = c_1 \Delta\sigma, \quad \Delta\lambda = \Delta\eta - H, \quad \lambda_2 = \lambda_1 + \Delta\lambda.$$

This direct solution algorithm is used by program card 3 (improved fix program) to compute the latitude and longitude of the receiver using the azimuth and range of the receiver from the Loran triplet vertex.

Details of the modifications made to Thomas' algorithm are contained in Reference 3.

G. Some Results

The following procedure was used to test the fixing algorithm: A more accurate version of the reverse solution algorithm (see Reference 3) was used to compute time delays at selected positions from Loran-C pairs. These computed time delays do not depend upon a fixing algorithm. The fixing algorithm was tested by determining the distance between the fix and the positions used to compute the time delays. Typical results are presented in Tables I through IV. As can be seen, all differences (Δ) are within 1 n.mi. The greatest difference (Δ = 0.92 n.mi. in Table IV) was obtained at a position located 2270 n.mi. from the triplet vertex.

Table I. 9940X/9940Y

Position		Calculated Time Delay		TI-59 Fix		
Lat	Long	9940X	9940Y	Lat (N)	Long (W)	Δ n.mi
24°N	122°W	27726.19	40912.76	23°59'55"	122°00'01"	0.08
26	122	27715.97	40998.39	25°59'57"	122°00'01"	0.05
28	122	27702.41	41117.84	28°00'00"	122°00'00"	0.00
30	122	27683.53	41291.85	29°59'59"	122°00'00"	0.02
32	122	27655.47	41555.46	32°00'00"	122°00'00"	0.00
34	122	27609.63	41959.57	34"00'00"	122°00'00"	0.00
36	122	27523.56	42544.11	36°00'00"	121°59'59"	0.01
38	122	27334.61	43248.22	38°00'00"	122°59'59"	0.01

Table II. 9940Y/9940W

Position		Calculated Time Delay		TI-59 Fix		
Lat	Long	9940Y	9940W	Lat (N)	Long (W)	Δ n.mi
37°N	122°W	42892.86	16257.23	36°59'59"	122°01'01"	0.02
37	125	43056.68	15765.13	37°00'00"	125"00'00"	0.00
37	128	43137.78	15327.12	37°00'00"	128°00'00"	0.00
37	131	43191.10	14970.77	37°00'00"	131°00'00"	0.00
37	134	43232.38	14683.74	37°00'00"	134°00'00"	0.00
37	137	43267.42	14449.40	37°00'00"	137°00'00"	0.00
37	140	43298.80	14254.02	37°00'00"	140°00'00"	0.01
37	143	43327.85	14087.43	37°00'01"	142°59'59"	0.02

Table III. 7930Z/9930X*

Position		Calculated Time Delay		TI-59 Fix		
Lat	Long	7930Z	9930X	Lat (N)	Long (W)	Δ n.mi
60°N	30°W	52437.86	28451.72	60°00'03"	29°59'32"	0.24
58	35	51960.93	28391.50	58°00'00"	34°59'48"	0.09
56	40	50992.37	28359.15	55°59'59"	39°59'54"	0.06
54	45	49292.46	28370.85	53°59'59"	44°59'57"	0.03
52	50	47165.60	28490.64	52°00'00"	49°59'57"	0.01
50	55	45236.59	29070.48	50°00'00"	55°00'00"	0.00
48	60	44505.60	30991.94	48°00'00"	60°00'00"	0.00
46	65	44475.70	33697.14	46°00'00"	65°00'00"	0.00
44	70	44588.91	36567.42	43°59'59"	69°59'59"	0.02

Table IV. 9930W/9930X*

Position		Calculated Time Delay		TI-59 Fix		
Lat	Long	9930W	9930X	Lat (N)	Long (W)	Δ n.mi
9°N	47°W	13058.04	36466.46	8°59'59"	46°59'22"	0.92
12	52	12984.71	37288.35	11°59'34"	51°59'37"	0.57
15	57	12898.73	38267.58	14°59'45"	56°59'47"	0.28
18	62	12793.91	39431.32	17°59'52"	61°59'54"	0.16
21	67	12656.52	40794.36	20°59'56"	66°59'57"	0.08
24	72	12451.30	42330.55	23°59'59"	71°59'59"	0.02
27	77	12097.12	43876.62	27°00'01"	77°00'00"	0.02
30	82	12973.95	44768.53	30°00'01"	82°00'06"	0.09

*The 9930 system was disestablished 30 September 1979. It is included here for illustration only.

H. References

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3. R. H. Shudde, "An Algorithm for Position Determination Using Loran-C Triplets with a BASIC Program for the Commodore 2001 Microcomputer," Technical Report NPS55-80-009, March 1980, Naval Postgraduate School, Monterey, CA 93940.

4. *LORAN HYPERBOLIC LOP FORMULAS AND GENERAL SPECIFICATIONS FOR LORAN-C* (20 June 1949) were obtained from G. R. Young, Acting Chief, Navigation Department, Defense Mapping Agency, Hydrographic/Topographic Center, Washington, D.C. by private communication, 5 March 1980.

5. Paul D. Thomas, "Spheroidal Geodesics, Reference Systems, and Local Geometry," PS-138, U. S. Naval Oceanographic Office, Washington, D.C., January 1970.

6. R. H. Shudde, "Position Determination with Loran-C Triplets and the Hewlett-Packard HP-67/97 Programmable Calculators," Technical Report NPS55-80-010, March 1980, Naval Postgraduate School, Monterey, CA 93940.

APPENDIX. Loran-C Station Parameters

The following list contains the pertinent parameters for each Loran-C station pair. This list was compiled from data in Reference 4. Each row contains the following information:

1. The Loran-C station pair designator
2. Δt, the sum of the coding delay plus one way baseline time, including the secondary phase correction for an all seawater path, in micrseconds.
3. The master station latitude.
4. The master station longitude.
5. The slave station latitude.
6. The slave station longitude.

In this report, the convention that a minus (-) sign denotes South latitudes and West longitudes has been followed throughout. Some users may wish to reverse the longitude convention so that (-) longitudes are East rather than West. This may be accomplished by consistently changing the sign of the longitude *everywhere* that it is required for data input; no program modifications are required. If the sign convention for longitude is reversed, care should be taken that the signs of all longitudes in the list are reversed. In columns 3 through 6 the latitudes and longitudes appear to be in decimal form, but the actual format is DDD.MMSSFF where

DDD	designates degrees,
MM	designates minutes,
SS	designates seconds, and
FF	designates hundredths of seconds.

```
4990X,15972.23,16.444395,-169.303120,20.144916,-155.530970
4990Y,34253.13,16.444395,-169.303120,28.234177,-178.170020
5930X,13131.88,46.482720,-067.553771,41.151193,-069.583909
5930Y,28755.02,46.482720,-067.553771,46.463218,-053.102816
5990X,13343.66,51.575878,-122.220224,55.262085,-131.151965
5990Y,28927.36,51.575878,-122.220224,47.034799,-119.443953
5990Z,42266.63,51.575878,-122.220224,50.362972,-127.212935
7930W,15068.02,59.591727,-045.102747,64.542658,-023.552175
7930X,27803.77,59.591727,-045.102747,62.175968,-007.042671
7930Z,48212.20,59.591727,-045.102747,46.463218,-053.102816
7960X,13804.45,63.194281,-142.483190,57.262021,-152.221122
7960Y,29651.14,63.194281,-142.483190,55.262085,-131.151965
7970W,30065.64,62.175968,-007.042671,54.482980,+008.173633
7970X,15048.10,62.175968,-007.042671,68.380615,+014.274700
7970Y,48944.53,62.175968,-007.042671,64.542658,-023.552175
7970Z,63216.30,62.175968,-007.042671,70.545261,-008.435869
7980W,12809.54,30.593874,-085.100930,30.433302,-090.494360
7980X,27442.38,30.593874,-085.100930,26.315501,-097.500009
7980Y,45201.88,30.593874,-085.100930,27.015849,-080.065352
7980Z,61542.72,30.593874,-085.100930,34.034604,-077.544676
7990X,12755.97,38.522061, 016.430596,35.312088, 012.312996
7990Y,32273.30,38.522061, 016.430596,40.582095, 027.520152
7990Z,50999.69,38.522061, 016.430596,42.033649, 003.121590
8970W,14355.11,39.510754,-087.291214,30.593874,-085.100930
8970X,31162.06,39.510754,-087.291214,42.425060,-076.493386
8970Y,47753.74,39.510754,-087.291214,48.364984,-094.331847
9930W,13695.51,34.034604,-077.544676,27.015849,-080.065352
9930X,36389.66,34.034604,-077.544676,46.463218,-053.102816
9930Y,52541.31,34.034604,-077.544676,41.151193,-069.583909
9930Z,68560.72,34.034604,-077.544676,39.510754,-087.291214
9940W,13796.90,39.330662,-118.495637,47.034799,-119.443953
9940X,28094.50,39.330662,-118.495637,38.465699,-122.294453
9940Y,41967.30,39.330662,-118.495637,35.191818,-114.481743
9960W,13797.20,42.425060,-076.493386,46.482720,-067.553771
9960X,26969.93,42.425060,-076.493386,41.151193,-069.583909
9960Y,42221.65,42.425060,-076.493386,34.034604,-077.544676
9960Z,57162.06,42.425060,-076.493386,39.510754,-087.291214
9970W,15283.94,24.48041 , 141.19290 ,24.17077 , 153.58515
9970X,36685.12,24.48041 , 141.19290 ,42.443700, 143.430906
9970Y,59463.19,24.48041 , 141.19290 ,26.362499, 128.085621
9970Z,80746.79,24.48041 , 141.19290 ,09.324566, 138.095523
9990X,14875.32 57.090988,-170.145981,52.494505,+173.105231
9990Y,32069.09,57.090988,-170.145981,65.144012,-166.531447
9990Z,46590.10,57.090988,-170.145981,57.262021,-152.221122
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Coverage of Loran-C Systems

Station	Location
4990	Central Pacific
5930	East Coast, Canada
5990	West Coast, Canada
7930	North Atlantic
7960	Gulf of Alaska
7970	Norwegian Sea
7980	Southeast U.S.A.
7990	Mediterranean Sea
8970	Great Lakes
9930	East Coast, U.S.A.
9940	West Coast, U.S.A.
9960	Northeast U.S.A.
9970	Northwest Pacific
9990	North Pacific

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